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A QUANTITATIVE ANALYSIS OF WATERSHED MORPHOLOGY USING GEO-SPATIAL APPROACH

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ABSTRACT

A study was conducted from Kumulur watershed, Trichy district, Tamil Nadu located at latitude and longitude of10°56'41.50"N-10°55'57.85"N&78°50'4.34"E-78°50'4.58"E, respectively with an areal extent of 848694 sq. m. The spatial data of Digital Elevation Model (DEM) of 4-meter resolution and satellite imagery(Google Earth) were used for the extraction of the watershed characteristics through morphometric analysis. The hydrological module of ArcGIS software was used to analyze the geospatial data. The watershed was therein delineated and the various parameters for the morphometric analysis viz., stream order (U), stream number (N_u), stream length (L_u), mean stream length (L_{sm}), stream length ratio (R_L), bifurcation ratio (R_b), drainage density (D_d), drainage texture (T), stream frequency (F_s), form factor (F_f), elongation ratio (R_e), circularity ratio (R_c), relief (R) and relief ratio (R_r)were calculated using the software. The basin morphometry shows the numerical analysis and mathematical quantification of different aspects of the watershed. The morphometric analysis includes aspects such as linear, areal & relief. The area and perimeter of the basin was calculated as 848694 sq. m. and 4923.06 m respectively. The total number of streams were found to be 213 and the total stream length of the watershed was calculated as 12833.6240 mof all the 4 stream orders forming a dendritic type of drainage pattern. The maximum length of the stream for the entire basin was observed to be 315.532 m. The bifurcation ratio of the basin varied from 1.543 to 5.000; the elongation ratio and the circularity ratio of the drainage basin were calculated as 0.5967 and 0.4398 respectively. The highest and lowest elevation of the watershed were observed to be 102.021 and 68.786 m which delivered the relief as 33.235 m and the relief ratio as 0.019.

KEYWORDS: Drainage Basin, Digital Elevation Model (DEM), Morphometric Analysis & ArcGIS Software

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Original Article

INTRODUCTION

Land and water are precious resources; they are the physical base of biomass on the earth. Preservation of land and water resources is very important to mitigate the increasing demand (Panhalkar *et al.*,2012). Nowadays planning and conservation of soil and water are very difficult due to the climate change, high expansion of inhabitant's, speedy urbanization with erratic distribution of rainfall, etc. Hence, there is a vital necessitate for the evaluation of every water resources because they play an important role in the sustainability of livelihood and local finances throughout the country. It is the main safeguard against drought and plays a central role in food security at local and national level as well as global levels. The ever rising population and urbanization is leading to over exploitation of the resources, thus exerting pressure on the limited public amenities, which are on the edge of collapse (Singh *et. al.*, 2013; Jha *et. al.*, 2007).

The watershed morphometry is the quantitative description and analysis of landforms as practiced in geomorphology that may be applied to a particular kind of landform or to drainage basin (Clarke, 1996 and Rudraiah *et. al.,* 2008). With regard to drainage basin, many quantitative measures have been developed to describe the valley side and channel slope, relief, area, drainage network type and extent, and other variables (Mesa, 2006). Physiographic characteristics of drainage basins like the size, shape, slope, drainage density, size and length of streams can be correlated with various important hydrologic phenomena (Magesh *et. al.,* 2011). Indices of the watershed morphometry can interpret the shape and hydrological inferences of the drainage basin.

Drainage basin morphometry attempts to explain and predict the long-term aspects of basin dynamics resulting in morphological changes within the basin and also delineate physical changes in drainage system with time in response to natural or anthropogenic disturbances (Kanth, T. A. 2012). They are the prerequisite for selection of water recharge site, watershed modeling, runoff modeling, watershed delineation, groundwater prospect mapping and geotechnical investigation.

Watershed characterization requires detail information for topography, drainage network, water divide, channel length, geomorphologic and geological setup of the area for proper watershed management and implementation plan for water conservation measures (Mesa, 2006; Wilson *et. al.,* 2012; Magesh and Chandrasekar, 2012). Morphometric analysis of a drainage basin necessitates preparation of the detailed drainage map and the aspects such as linear, areal and relief.

Digital Elevation Model are a very accurate tool for morphometrical parameter evaluation and watershed delineation for watershed management. In the present study, the hydrological analysis of the watershed at AEC & RI campus were carried out for water resource management through the use of DEM generated from the ArcMap software as the use of GIS enables rapid, precise and inexpensive alternative for morphometric analysis (Sreedevi *et. al.,* 2009; Magesh *et. al.,* 2011; Pareta and Pareta, 2011; Magesh *et. al.,* 2013).

STUDY AREA

The watershed is located at the Agricultural Engineering College& Research Institute, Kumulur, Trichy district, Tamil Nadu, India. The latitude and longitude of the selected watershed lies between 10°56'41.50"N&78°50'4.34"E - 10°55'57.85"N&78°50'4.58"E (Figure 1) which covers an areal extent of 848694 sq.m. The average annual rainfall of the study area is 858 mm and the temperature varies from 25˚C to 32˚C.

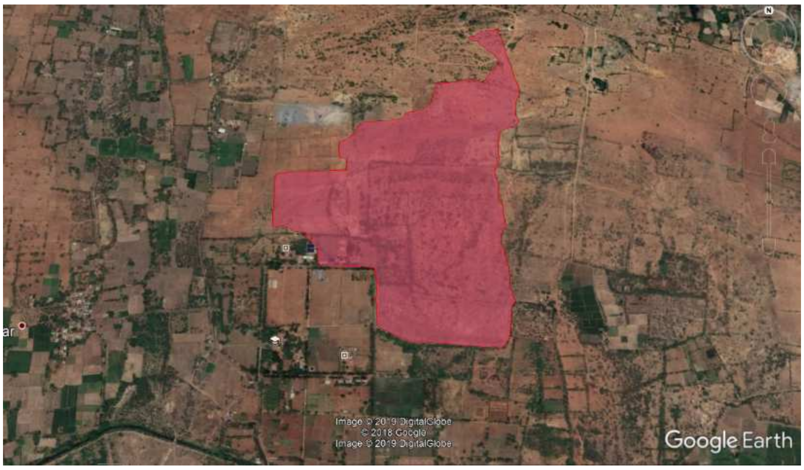

Figure 1: Study Area (Watershed) – *Google Earth Interface*

MATERIALS & METHODOLOGY

The ground truth survey was conducted in the field of study and handheld GPS of positional accuracy 2 to 5 meter was used to collect field data points. The point features were collected along the ridgeline of the study area using Terra Sync software. The results from the GPS was then exported in the Excel Spreadsheet where it was saved in ***.csv*** (comma delimited) file format.

Google Earth Interface

The ***.csv*** file was then imported and displayed on Google Earth as shown in Figure 2. The data points were connected using **Add Polygon** tool. The resultant polygon generated the Region of Interest (study area). Thus, the polygon was exported from Google Earth in. ***.kml*** file format. Using Add Path tool, points were added over the entire selected area and was saved in ***.kml*** file format.

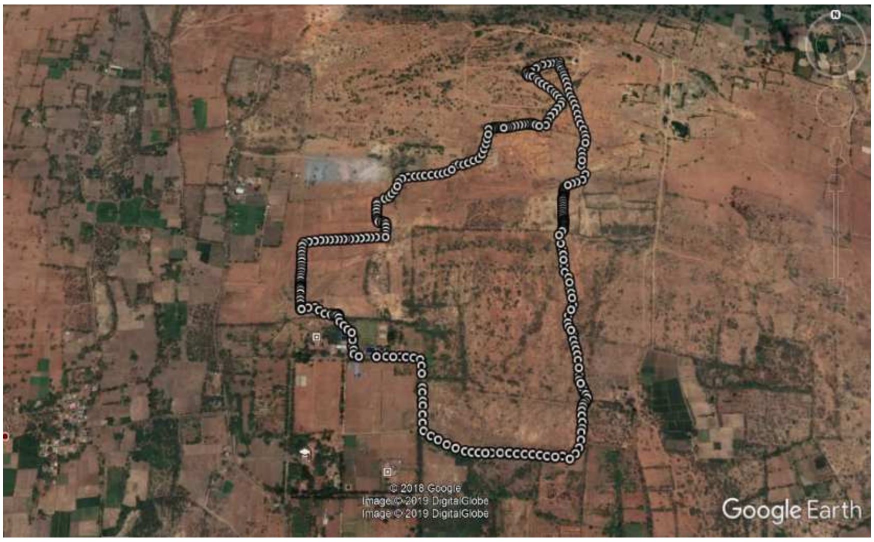

Figure 2: Field Data Points Collected Using Handheld GPS

DEM Generation

The polygon feature***.kml*** file was converted into a shape file in ArcMap 10.1, whereas the point feature ***.kml*** file was converted into Excel Workbook file format prior to adding the file into ArcMap software wherein the output layer of point shape file was generated. The Digital Elevation Model (DEM) was generated using Triangulated Irregular Network (TIN) interpolation. The methodology flow chart of the DEM generation is shown in Figure 3.

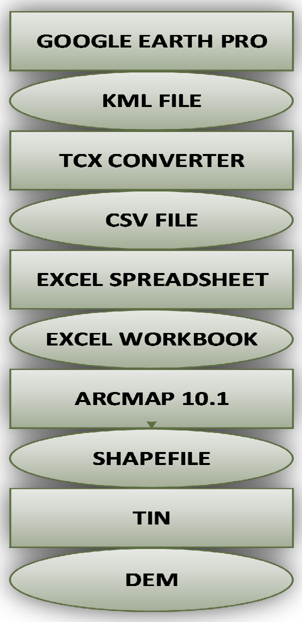

Figure 3: Methodological Flow Chart for DEM Generation

Analysis

The generated DEM was pre-processed using the **Spatial Analyst toolbox** and the ***Hydrology*** tools were used to fill the depressions, to generate flow direction and flow accumulation. The threshold value applied in the cells with high accumulated flow for the creation of stream network was set as 100. Morphometric analysis of a drainage system requires delineation of all existing streams. The stream delineation was done digitally in GIS system. The different morphometric parameters were determined and are namely, stream order (U), stream number (N_u), stream length (L_u), mean stream length (L_{sm}), stream length ratio (R_L), bifurcation ratio (R_b), drainage density (D_d), drainage texture (T), stream frequency (F_s), form factor (F_f), elongation ratio (R_e), circularity ratio (R_c), relief (R) and relief ratio (R_r). The methodologies adopted for the computation of morphometric parameters are given in Table 1 (Singh *et. al.,* 2014).

Table 1: Morphometric Parameters and its Computation

S.No.	Aspects	Parameters	Formulae
	Linear		
1.		Stream order (U)	Hierarchical rank
2.		Stream length (L_u)	Length of the stream
3.		Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$
4.		Stream length ratio (R_L)	$R_L = L_u/(L_u\text{-}1)$
5.		Bifurcation ratio (R_b)	$R_b = N_u/N_u+1$
6.		Mean bifurcation ratio (R_{bm})	R_{bm} = avg of R_b of all order
	Areal		
7.		Drainage density (D_d)	$D_d = L_u/A$
8.		Drainage texture (T)	$T = N_u/P$
9.		Stream frequency (F_s)	$F_s = N_u/A$
10.		Elongation ratio (R_e)	$R_e = D/L_b$
11.		Circularity ratio (R_c)	$R_c = A/A_1$
12.		Form factor (F_f)	$F_f = A/L_b^2$
	Relief		
13.		Relief (R)	$R = H - h$
14.		Relief ratio (R_r)	$R_r = R/L_b$

Where, U = stream order; L_u= stream length; N_u = stream number; L_{sm} = mean stream length; R_L = stream length ratio; R_b= bifurcation ratio; R_{bm}= mean bifurcation ratio; D_d= drainage density; A = area of the basin; T = drainage texture; P = perimeter of the basin; F_s = stream frequency; R_e = elongation ratio; D = diameter of the circle of the same area as that of the drainage basin; L_b = maximum flow length; R_c= circularity ratio; A_1 = area of the circle having same perimeter as that of the drainage basin; F_f = form factor; R = relief; H = highest elevation; h = lowest elevation; R_r = relief ratio.

RESULTS AND DISCUSSIONS

Digital Elevation Model (DEM)

A Triangulated Irregular Network (TIN)is a vector-based representation of the physical land surface, made up of irregularly distributed nodes and lines with three-dimensional coordinates (x-, y- & z-coordinates) that are arranged in a network of non-overlapping triangles.

A TIN used to represent terrain is often called a Digital Elevation Model (DEM). A DEM can be interpolated from a TIN. The interpolated DEM of the study area using TIN is shown in Figure 4. The figure reads the elevation in metres which ranges between 68.786 and 102.021.

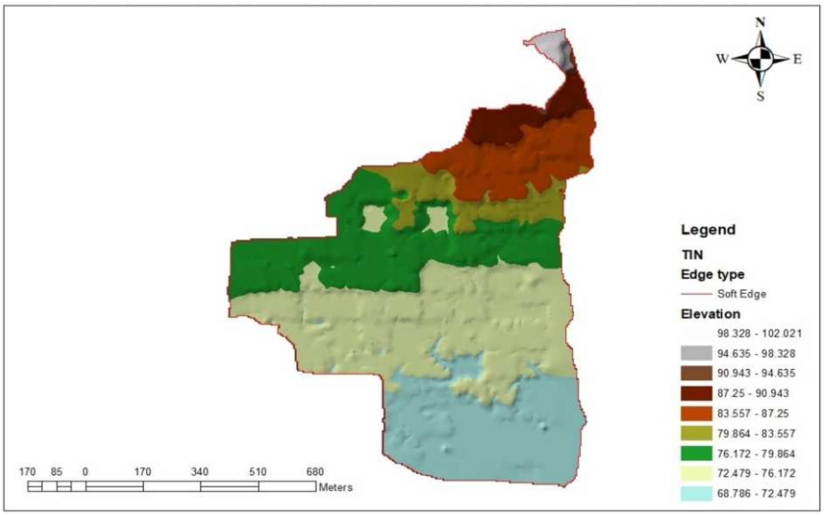

Figure 4: Digital Elevation Model (DEM)

Area and Perimeter of the Drainage Basin

The area and perimeter of the basin was calculated as 848694 sq. m. and 4923.06 m respectively. The perimeter describes the distance around the basin. The calculated results are shown in Figure 5. Since the study is concentrated on micro level, the area of watershed is considered very small.

Table

polygon

FID	Shape *	Id	Area	Perimeter
0	Polygon	0	848694	4923.06

0 (0 out of 1 Selected)

polygon

Figure 5: Drainage Basin – *Attribute Table*

Stream Order (U) and Stream Number (N_u)

Stream order of the drainage basin is the successive assimilation of the streams within a drainage basin. In the present study the stream ordering has been ranked based on a method proposed by Strahler. The concept of stream order assigns numerical designations that indicate where in a watershed drainage system a certain stream segment lies and classifies the types of streams based on their number of tributaries. All links without any tributaries are assigned an order of 1 and are referred to as first order. The streams of first order are dominated by overland flow; they have no upstream concentrated flow. The intersection of two first-order links will create a second-order link, the intersection of two second-order links will create a third-order link, and so on (Nag 1998). The entire basin has first order to fourth order forming a dendritic drainage pattern as depicted in Figure 6. Presence of dendritic pattern shows homogeneity and uniformity in soil type and topography (Rawat *et. al.*,2017). The total number of streams in the entire drainage basin was estimated as 213. The number of streams of each order from lowest order to highest order are 117, 54, 35 & 7 as shown in Figure 7.

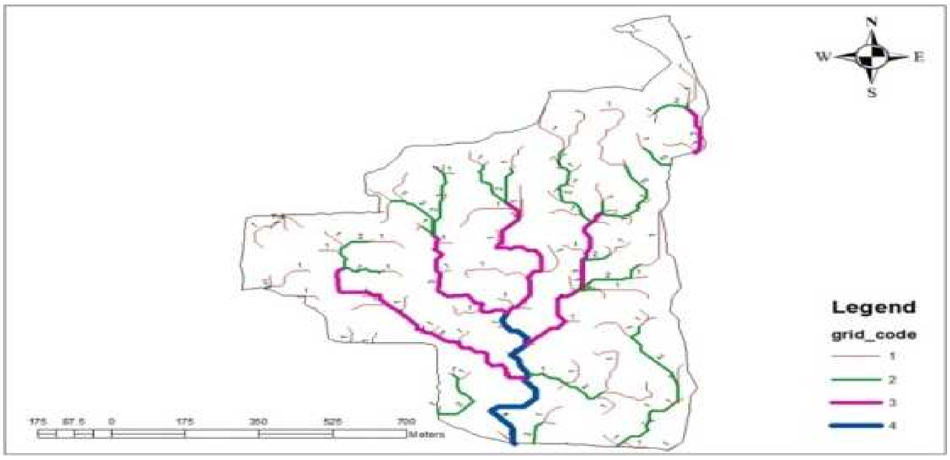

Figure 6: Stream Order

Table

streamnumber.txt

grid_code	Count_grid_code	Sum_arcid
1	117	11987
2	54	5407
3	35	4150
4	7	1247

0 (0 out of 4 Selected)

streamnumber.txt

Figure 7: Stream Number – *Attribute Table*

Stream Length (L_u)

Stream length is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces. Longer lengths of streams are generally indicative of flatter gradients. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. The total length of the streams in the entire basin were derived from the ArcMap software and it was about 12833.6240 m. The maximum and minimum stream length were 315.532 and 2.184 m as depicted in Figure 8. The stream length for each stream order is presented in Table 2.

Table 2: Stream Order (U) and Stream Length (L_u)

Stream Order (U)	Stream Length (L_u) (m)
1	6650.8872
2	3177.7122
3	2394.9669
4	610.0576
Total	**12833.6240**

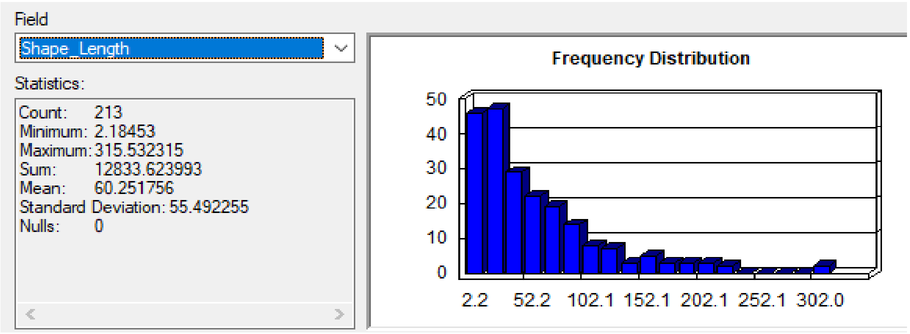

Figure 8: Statistics of Streamlines(*Shape_Length*)

Mean Stream Length (L_{sm})

Mean stream length is the ratio between the stream lengths of order 'U' to the number of streams in its respective order. It has been observed that with the increase in stream order, there is an increase in mean stream length. The calculated results are tabulated and presented below in Table 3.

Table 3: Mean Stream Length (L_{sm})

Stream Order (U)	Stream Length (L_u) (m)	Stream Number (N_u)	$L_{sm} = L_u/N_u$(m)
1	6650.8872	117	56.8452
2	3177.7122	54	58.8465
3	2394.9669	35	68.4276
4	610.0576	7	87.1511

Stream Length Ratio (R_L)

Stream length ratio is the ratio between the total stream lengths of one order to the next lower order of stream segment. An increasing trend in the stream length ratio from lower order to the higher order indicates their mature geomorphic stage. From the calculated results, the stream length ratio with each increase in order has shown some fluctuations. The length ratio has no constant values to form a geometric series which is mainly due to variations in the nature of rock and terrain conditions. The calculated results are presented in Table 4.

Table 4: Stream Length Ratio Table (R_l)

Stream Order (U)	Stream Length Ratio (R_L)
2 / 1	0.4778
3 / 2	0.7537
4 / 3	0.2547

Bifurcation Ratio (R_b) and Mean Bifurcation Ratio (R_{bm})

The term bifurcation ratio may be defined as the ratio of the number of stream segments of a given order to the number of segments of the successive higher order. The R_b is a dimensionless property and is used to interpret structural deformity of watershed area. Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern (Strahler, 1964). The higher value of R_b would indicate strong structural control of watershed for stream characteristics. The bifurcation ratio for the successive orders from 1^{st} to 4^{th} order was found to be 1:2.167, 1:1.543 and 1:5.000. Thus, the mean R_b was calculated as 2.903 which is an indication for the geological structures to be disturbing the drainage pattern. The estimated values are tabulated below in Table 5.

Table 5: Bifurcation Ratio (R_b) and Mean Bifurcation Ratio (R_{bm})

Stream Order (U)	Bifurcation Ratio (R_b)
1 / 2	2.167
2 / 3	1.543
3 / 4	5.000
Average (R_{bm})	**2.903**

Drainage Density (D_d)

Drainage density is the total stream length of all orders per drainage area and controlled by the slope gradient and relative relief of the basin. It is a measure of the degree of fineness or coarseness of a drainage network pattern *i.e.*, an indicator of the terrain configuration (Ezeh *et. al.*, 2019). The drainage density of the study area has been calculated and the value is depicted in Figure 9. Low drainage density indicates the maximum part of the basin is covered by the permeable subsurface material and moderate vegetation cover. The drainage density map was generated using the ***Line density*** tool from **Spatial Analyst** toolbox and is shown in figure 10.

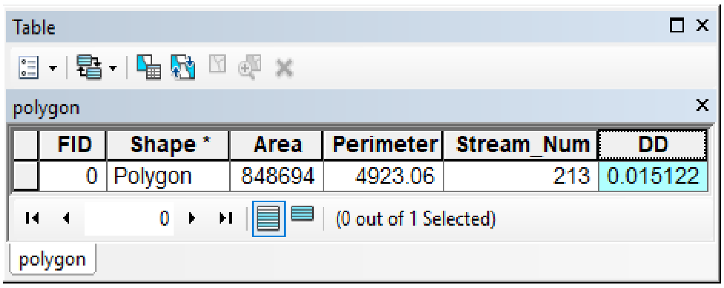

Figure 9: Drainage Basin – *Attribute Table*

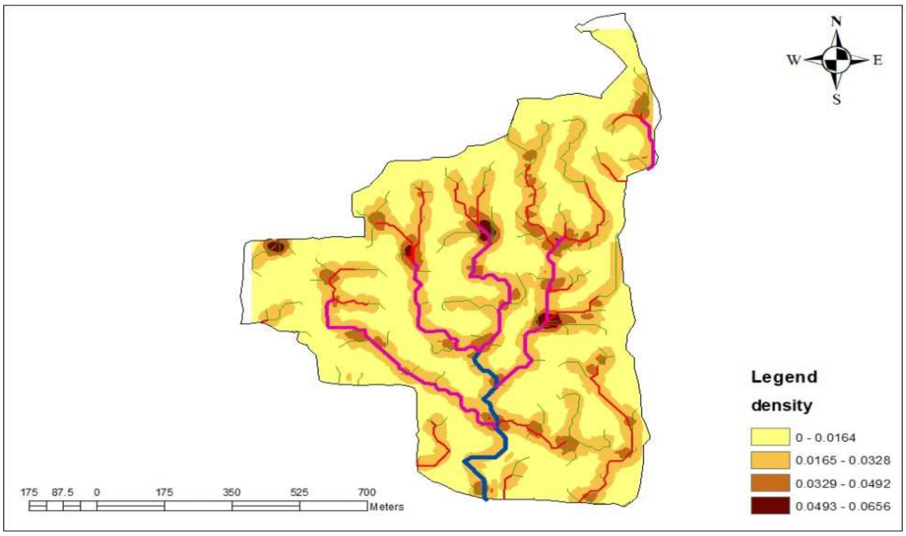

Figure 10: Drainage Density Map

Stream Frequency (F_s)

Stream frequency is the total number of channel segments of all stream orders per unit area of the entire basin. Thus, the calculated value of stream frequency is 0.00025 which signifies that the soil is highly permeable. The F_s value of the watershed are exhibiting positive correlation with the drainage density indicating the increase in stream population with an increase in drainage density.

Drainage Texture (T)

Drainage texture is the total number of stream segments of all order in a river basin to the perimeter of the basin. The unit of drainage texture is m^{-1}. Smith (1950) has classified the drainage density into five different textures and they are namely, <2 (very coarse), between 2-4 (coarse), between 4-6 (moderate), between 6 and 8 (fine) and >8 (very fine). In the study area, the drainage density falls under the category of very coarse drainage texture. An increase in drainage texture indicates increase in dissection which leads to erosion. The calculated value for the drainage texture is 0.04326.

Elongation Ratio (R_e)

Elongation ratio is the ratio between the diameters of the circle of the same area as the drainage basin to the maximum flow length of the basin. The maximum length (L_b) of the basin can be defined as the longest dimension of the basin parallel to the principal drainage line. It is the length of the line from a basin mouth to a point on the perimeter which rests furthest from the outlet (Partha Pratim Adhikary *et. al.*, 2018). The values of R_e generally varies from 0.6 – 1.0. The index value of 1.0 are typical of regions of very low relief indicates a circular basin, whereas values in the range 0.6 – 0.8 are usually associated with high relief and steep ground slope indicating an increase in elongation. These values can be grouped into three categories namely circular (>0.9), oval (0.9-0.8) and elongated (<0.7). The elongation ratio of the basin is 0.5967. The maximum flow length (L_b) was derived from the raster DEM in ArcMap software using **Hydrology** tool ***Flow Length*** command(figure 11).

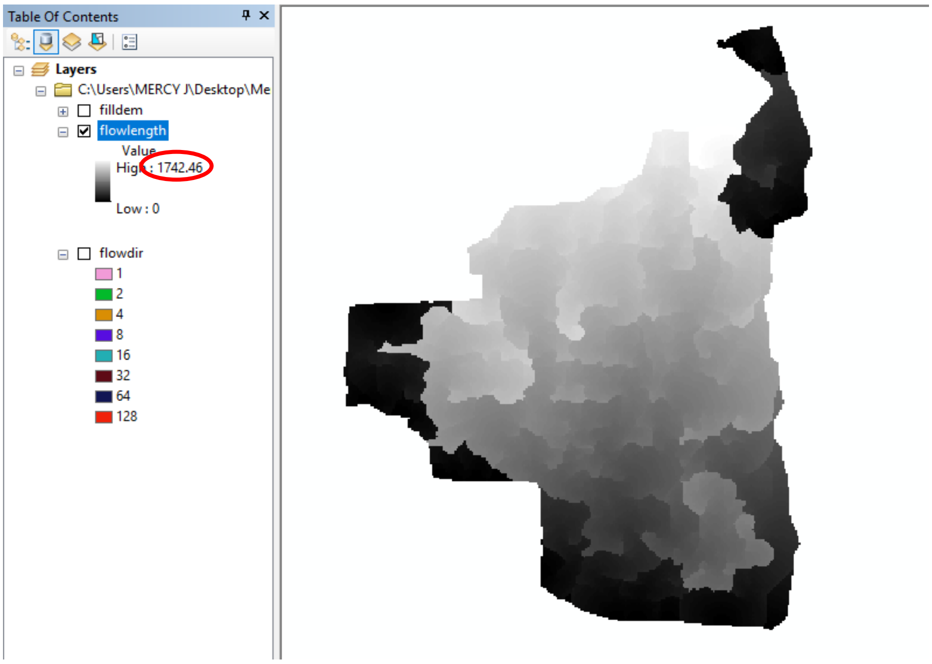

Figure 11: Maximum Flow Length (L_b)

Circularity Ratio (R_c)

Circularity ratio is the ratio between the areas of a watershed to the area of the circle having the same circumference as the perimeter of the basin. R_c is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. Generally, the R_c value falls under 0.2 to 0.8 where the high value of circularity ratio shows the late maturity stage of topography (Yangchan *et. al.*, 2015). The calculated circularity ratio of the basin is 0.4398 which indicates the basin as strongly elongated and has low discharge of runoff and highly permeable subsoil condition.

Form Factor (F_f)

Form factor is a ratio of watershed area to the square of the basin length of the drainage basin. The form factor indicates the flow intensity of a basin for a defined area. The range values for form factor are <0.78 (elongated) and >0.78 (circular). Basins with high form factor experience larger peak flows of shorter duration, whereas elongated basin with low form factor experience smaller peak flows of longer duration (Sukristiyanti *et. al.,* 2018). The calculated form factor value for the basin is 0.2795 indicating that the shape of the basin is elongated.

Relief (R) and Relief Ratio (R_r)

Relief is the elevation difference between the highest and lowest points of a drainage basin. Relief ratio is the ratio between the total relief of a basin and the longest dimension of a basin parallel to the principal drainage line. It measures the overall steepness of a drainage basin and is an indicator of the intensity of the erosion processes on the slope of the basin. It is noted that the high values of R_r indicate steep slope and high relief, while the lower values indicate the presence of basement rocks exposed in the form of small ridges and mounds with a lower degree of slope. The calculated values for R and R_r is 33.235 m and 0.019, respectively.

CONCLUSIONS

Watershed as a basic unit of morphometric analysis has gained importance because of its topographic and hydrological unity. The power of GIS and open-source data to characterize a drainage basin has been demonstrated using the Digital Elevation Model (DEM) with the very high accuracy of mapping and measurement which thus proves to be a competent tool in morphometric analysis.

The morphometric analysis of the drainage network of the basin exhibits as mainly dendritic type which indicates the homogeneity in texture and lack of structural control and helps understand various terrain parameters. The total length of stream segments is maximum in first order streams and decreases as the stream order increases. The law of lower the order higher the number of streams is implied throughout the catchment. The variation in stream length ratio and bifurcation ratio might be due to the changes in slope, topography and geometric development. The stream frequency value of the watershed are exhibiting positive correlation with the drainage density indicating the increase in stream population with an increase in drainage density. The drainage density of the basin described the drainage texture as very coarse. The value of the elongation and circularity ratio identified the drainage basin as elongated with high relief, steep ground slope and highly permeable subsoil condition.

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